Three-regime threshold error correction models and the law of one price: the case of European electricity markets

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Key idea

Assess integration in European electricity forward markets allowing for the possibility that convergence may not always be operational:

- ✓In forward markets interdependencies may occur only when the spread between prices is larger than the differences in the perceived risks.

Contents

Motivation

Exact quantification of speeds of adjustment toward the equilibrium as a crucial step for policy indications

Quantify what proportion of price differentials is linked to structural reasons and what part is due to market inefficiencies.

•Cross- border contracts are an indirect hedging instrument.

Investigate prices convergence using a strategy that is robust and opportune for the problem at stake.

•Band of non-adjustment of small deviations from the equilibrium inside a regime of cointegration.

Considered variables

– The data used in the present study are (logs of) baseload week-ahead electricity prices for the power exchanges of:

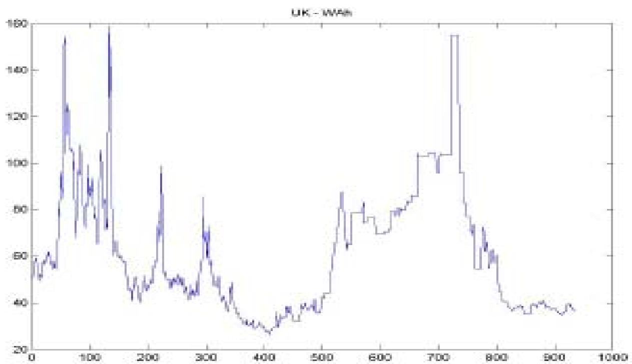
- United Kingdom (UK)
- Germany (GE)
- France (FR)
- The Netherlands (NE).

– The data sets cover the period June 2005 – September 2009; for Germany the sample periods starts in September 2007.

Considered variables\ Plot of series

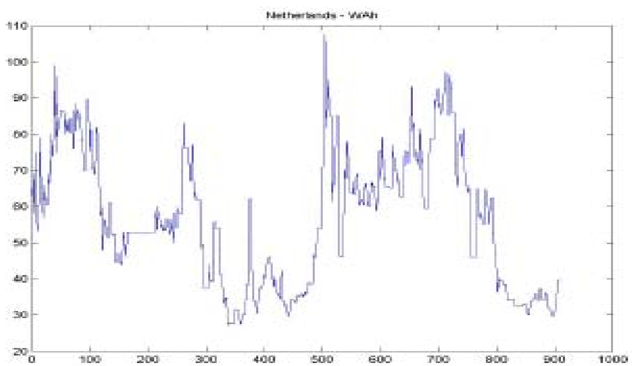
Typical features of electricity prices include pronounced volatility and spikes.

Prices series E/Kwh are reported in the Figures below:

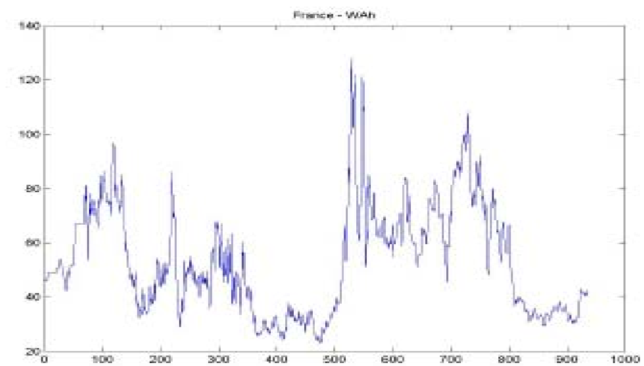


(a) United Kingdom

(b) Germany



(c) Netherlands



(d) France

Considered variables\ Data analysis

- ADF test statistics document that log-transformed series are I(1) at the 5% level, except in the case of France for which the null is not rejected at the1% level

Variable	UK	GE	NE	FR
ADF	-2.569	2.638	-2.737	-3.343*

- Correlations of growth rates are considered to avoid problems of spurious correlation.
  - The highest correlation is between Germany and France.

	UK	GE	NE	FR
UK	1.000			
GE	.100	1.000		
NE	.115	.236	1.000	
FR	.215	.635	.189	1.000

Choice of the models

– The hypothesis of market efficiency would imply that the slope of the equilibrium is one;

– Arbitrage opportunities and therefore interdependencies in prices would arise only when the spread between prices is sufficiently large.

– Main features of the scatter plots of series reflect the facts stated above:

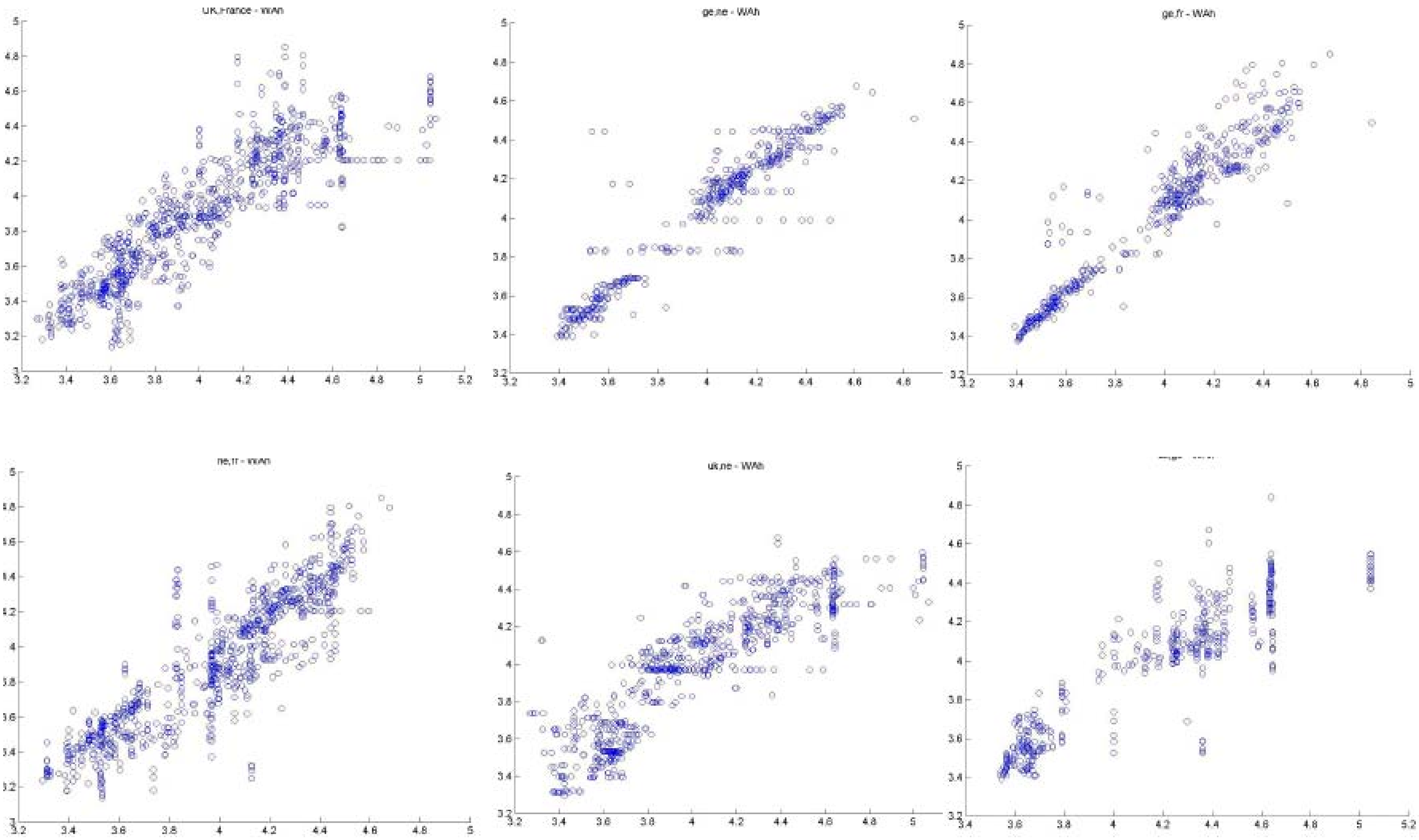
  – The largest amount of points can be observed around a line of approximately 45° slope;

  – Some observations are spread elsewhere in the graph.

– VECM seems to be a reasonable tool for estimating dynamic and long-run coefficients, and testing whether the cointegrating vector is [1 -1];

– TVECM may be a more appropriate tool in that it allows for the speeds of adjustment to differ for observations close to the 45° line and spread elsewhere.

Choice of the models\ Scatter plots of pair of prices



TVECM are the basic tool used in the analysis.

A multivariate TVECM is proposed by Hansen and Seo (2002) as:

$$\Delta_1 x_t = A_1^{'} X_{t-1}(\beta) d_{1,t}(\beta,\gamma) + A_2^{'} X_{t-1}(\beta) d_{2,t}(\beta,\gamma) + e_t$$

where

$$X_{t-1} = \begin{pmatrix} 1 & z_{t-1}(\beta) & \Delta x_{t-1} & \ldots & \Delta x_{t-p+1} \end{pmatrix}$$

and

$$d_{1,t}(\beta,\gamma) = 1(z_{t-1}(\beta) \leq \gamma)$$
$$d_{2,t}(\beta,\gamma) = 1(z_{t-1}(\beta) > \gamma)$$

Econometric approach\ Model specification 2

To allow for a band of inaction I slightly modify the previous model by defining:

$$d_{1,t}(\beta,\gamma) = 1\left(\left|z_{t-1}(\beta)\right| \leq \gamma\right)$$
$$d_{2,t}(\beta,\gamma) = 1\left(\left|z_{t-1}(\beta)\right| > \gamma\right)$$

This is a restricted version of a three-regime TVECM in which threshold and loadings out of the inaction band are symmetric.

Econometric approach\ Estimation

The model is estimated by conditional MLE.

The estimation procedure is:

- First a grid search is executed over the two dimensional space (β, γ) ;
- Letting (β, γ) fixed, for each possible value of their support conditional MLE of (A_1, A_2, Σ) is obtained;
- The estimates of β and γ are those that minimize the maximum likelihood;
- Estimates of (A_1, A_2, Σ) are the corresponding values.

Econometric approach\ Testing for threshold

To test for threshold cointegration instead of the linear one a LM-like statistic robust to heteroskedasticity is used.

•The ML statistic is evaluated at point estimates under the null of linearity;

• γ is not defined under the null of linearity, therefore the proposed statistic is:

$$\sup_{\gamma} LM(\beta, \gamma)$$

•Residual bootstrap is applied to obtain critical values and the corresponding p-values.

Implementation

•The cointegrating relation $z_t(\beta)$ determines the switch between the regimes;

•Cross-border trading between country A and country B is undertaken only when the weighted price ratio exceeds the difference in risks:

$$F_A / F_B^{\beta} \geq e^{-\gamma} \quad if \quad \log(F_A / F_B^{\beta}) < 0$$

$$F_A / F_B^{\beta} \leq e^{-\gamma} \quad if \quad \log(F_A / F_B^{\beta}) > 0$$

•For both β and γ parameters the grid points are 300.

Implementation – UK-FR pair

The empirical evidence supports the theoretical hypothesis. There exists a "neutral band"; overall prices appear to be cointegrated.

✓The existence of a direct interconnection may matter for the results.

•The estimated threshold is γ= .351 (i.e. 1:420 define the bounds for the ratio of the weighted prices);

•Cointegrating coefficients are β_{VECM} = 1.158 and β_{TVECM} = 1.059, which is close to 1;

•Non-arbitrage state dominates the pooled data set (the equilibrium term is
• inside the bounds the 91% of times) ;

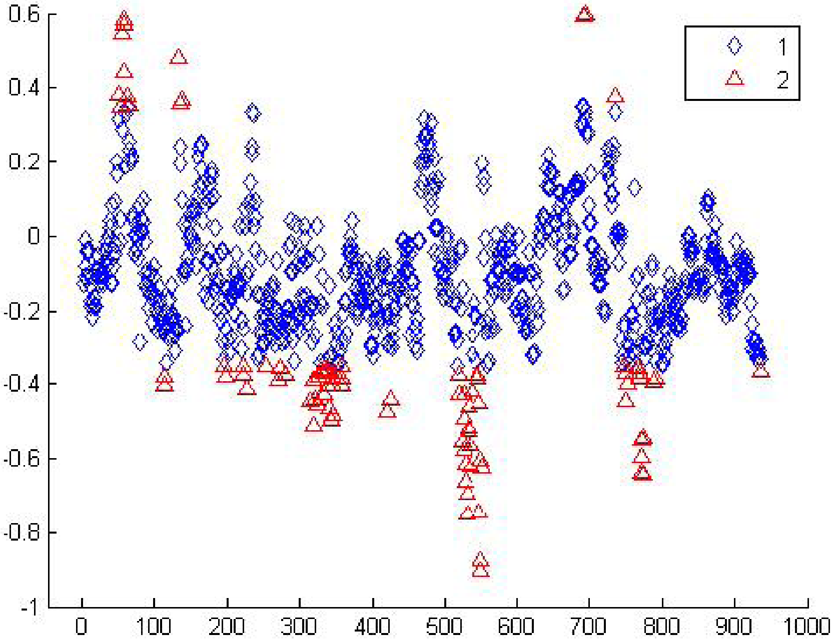
•Outside the bounds the adjustment coefficient of the UK equation is significant;

•In the remaining cases the loadings are insignificant or numerically very small;

•The Wald test for the equality of adjustment coefficients reject the null.

Implementation – UK-FR pair

Equilibrium term by regime



Estimates of loadings and intercepts, and information criteria

	VECM		TVECM			
			REGIME1		REGIME 2	
Equation1	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
λ	-0.045	-0.013	-0.024	-0.014	-0.141	-0.041
μ	-0.023	-0.007	-0.001	-0.002	-0.057	-0.02
Equation2						
λ	0.075	-0.013	0.054	-0.018	0.067	-0.043
μ	0.037	-0.007	0.009	-0.003	-0.022	-0.017
AIC	-4900.009		-4906.312			
BIC	-4892.246		-4890.786			

Implementation – GE-NE pair

The estimated model seems to be appropriate for capturing the adjustment process

✓The markets are interconnected and the voume of exchanges largely exceeds the previous case.

•The estimated threshold is γ= .248 (i.e. 1.281 are the bounds for F_{GE}/ F_{FR}^β for the ratio of the weighted prices), which is lower than .35 and seems to reflect the higher level of interconnections;

•Cointegrating coefficients are β_{VECM} = .968 and β_{TVECM} =. 944;

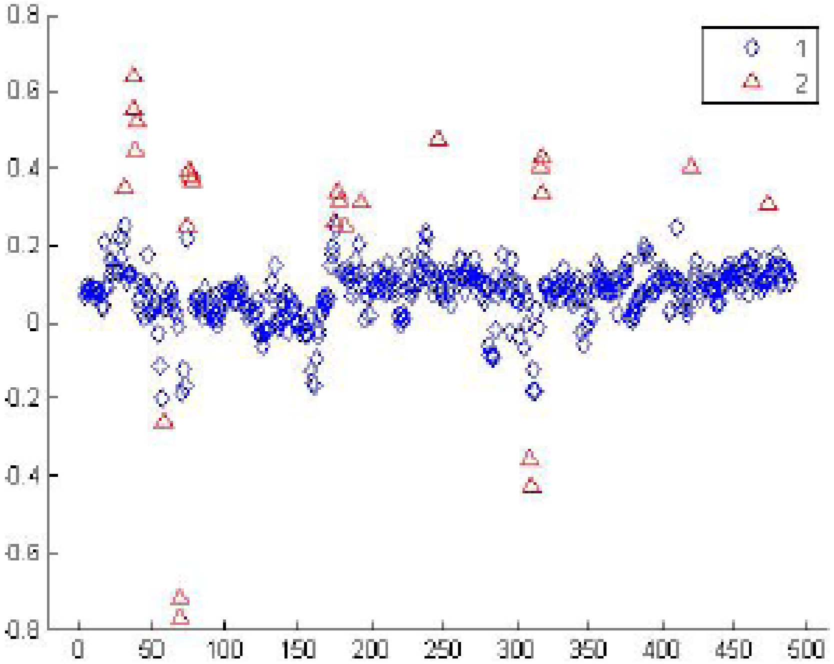
•The equilibrium term is inside the bounds the 94% of times;

•The adjustment coefficients are either small or insignificant in regime 1;

•One dynamic parameter of the first equation is strangely large (however The estimate is imprecise due to the small amount of observations in state 2)

Implementation – GE-NE pair

Equilibrium term by regime



Estimates of loadings and intercepts, and information criteria

	VECM		TVECM			
			REGIME1		REGIME 2	
Equation1	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
λ	-0.085	-0.049	-0.045	-0.076	-0.001	-0.043
μ	0.016	-0.01	0.007	-0.008	-0.041	-0.017
Equation2						
λ	0.29	-0.049	0.135	-0.036	0.534	-0.101
μ	-0.052	-0.01	-0.01	-0.004	-0.084	-0.025
AIC	-2631.046		-2670.121			
BIC	-2625.617		-2625.618			

Implementation – GE-FR pair

Estimates lead to less clear-cut results.

✓The volume of exchanges between these markets leads to significant links between these markets.

•Point estimate β_{VECM} =.887 (which is not statistically different from 1) and
•β_{TVECM} =.982;

•The threshold estimate is γ= .244 (numerically close to the previous case);

•The neutral regime dominates the pooled data set (95% of cases);

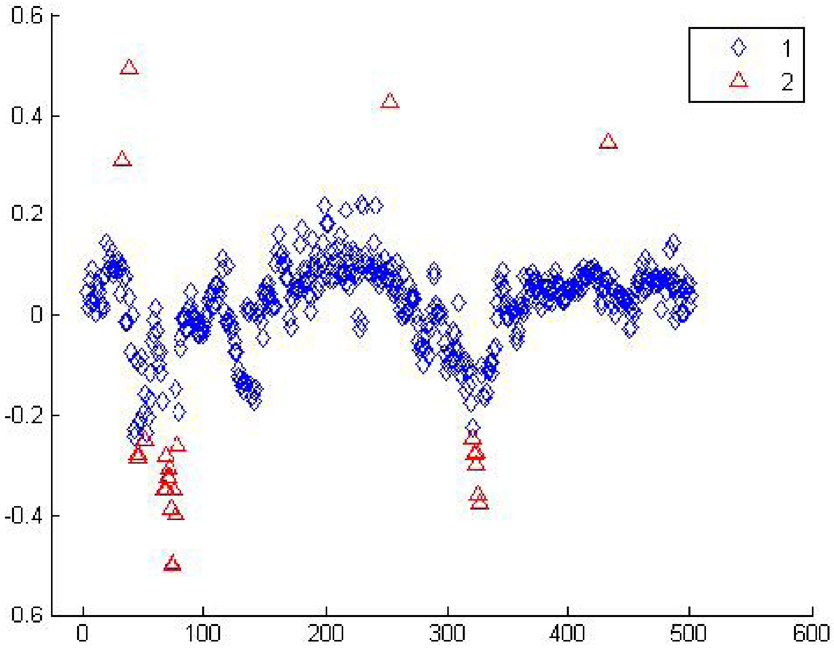
•In the first regime the loading of the France equation is significant, and in regime 2 only Germany appears to adjust toward the equilibrium;

•Strangely in that regime the loading of the second equation, although not significant at the 5% level, is negative (when $\log(F_{GE})/\beta\log(F_{FR})$ is large one would expect F_{FR} to rise);

•By omitting the threshold the loadings of the linear VECM are not significant.

Implementation – GE-FR pair

Equilibrium term by regime



Estimates of loadings and intercepts, and information criteria

	VECM		TVECM			
			REGIME1		REGIME 2	
Equation1	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
λ	-0.103	-0.071	0.023	-0.044	-0.641	-0.181
μ	0.041	-0.03	0.001	-0.003	-0.165	-0.047
Equation2						
λ	0.046	-0.071	0.117	-0.048	-0.235	-0.148
μ	-0.018	-0.03	-0.003	-0.003	-0.053	-0.047
AIC	-2721.046		-2750.333			
BIC	-2715.461		-2739.163			

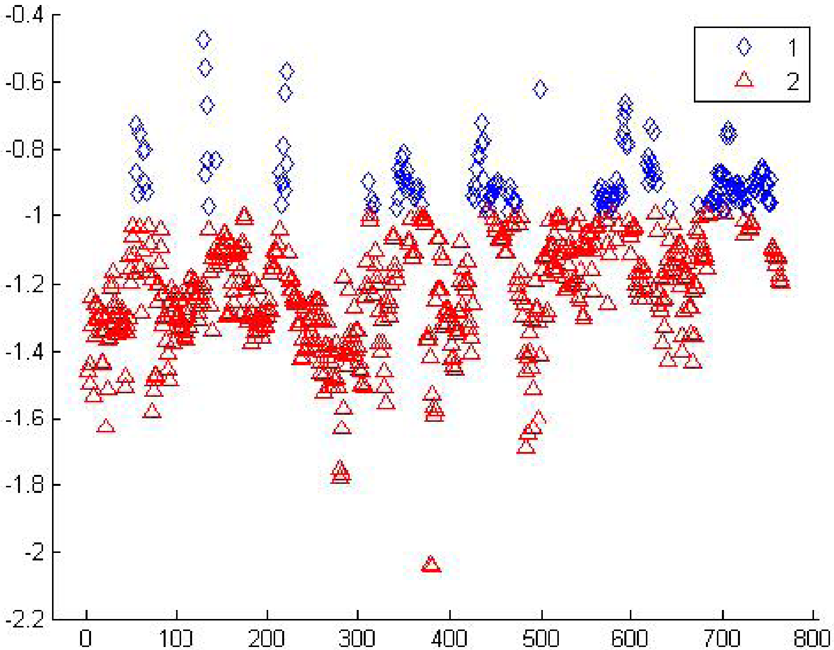
Implementation – UK-NE pair

The empirical evidence contrasts whith the expectations.

- The value β_{VECM} is significantly larger than 1 and β_{TVECM} = 1.30;
- γ= .98, which is much larger than the previous estimates;
- Despite the large threshold the first regime holds 24% of times only;
- In the first regime the loading and intercept estimates of the first equation are large;
- Outside the bounds the adjustment coefficients and the constant are significant but point estimates are small.

Implementation – UK-NE pair

Equilibrium term by regime



Estimates of loadings and intercepts, and information criteria

	VECM		TVECM			
			REGIME1		REGIME 2	
Equation1	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
λ	-0.058	-0.017	-0.392	-0.102	-0.053	-0.018
μ	-0.049	-0.015	-0.36	-0.094	-0.064	-0.022
Equation2						
λ	0.07	-0.017	0.077	-0.06	0.098	-0.03
μ	0.059	-0.015	0.077	-0.055	0.116	-0.036
AIC	-4021.665		-4033.967			
BIC	-4014.61		-4019.855			

Implementation – NE-FR pair

The estimates seem to be the other way round than what expected.

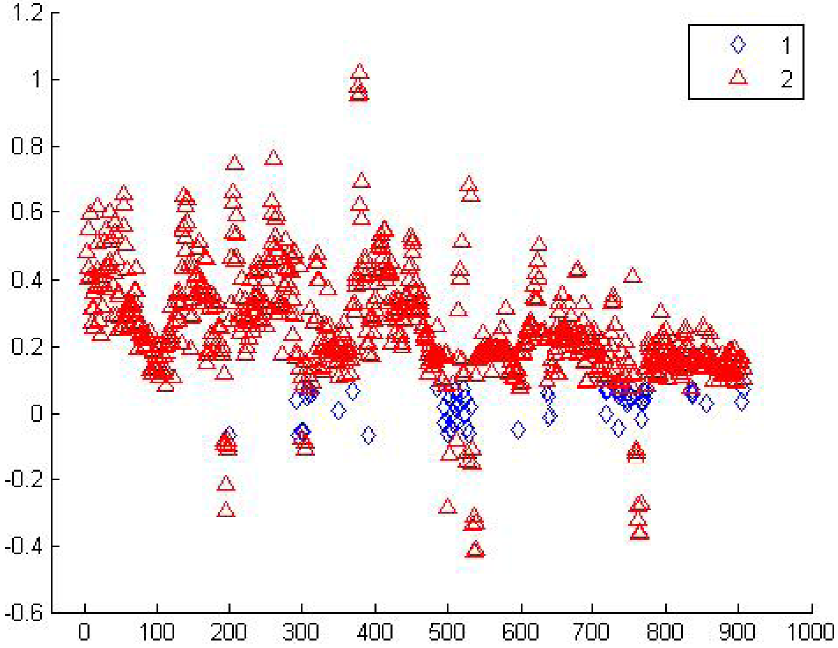
•In this case the estimated threshold is very small, γ= .07;

•The equilibrium term is inside the bounds the 7% of times only;

•Loading estimates suggest that the adjustment toward the equilibrium applies
• only inside the bounds.

Implementation – NE-FR pair

Equilibrium term by regime



Estimates of loadings and intercepts, and information criteria

	VECM		TVECM			
			REGIME1		REGIME 2	
Equation1	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
λ	-0.08	-0.024	-0.107	-0.2	-0.068	-0.026
μ	0.032	-0.01	0.019	-0.01	0.014	-0.006
Equation2						
λ	0.069	-0.024	1.351	-0.566	0.051	-0.021
μ	-0.028	-0.01	-0.072	-0.029	-0.011	-0.006
AIC	-4726.967		-4739.906			
BIC	-4729.309		-4724.592			

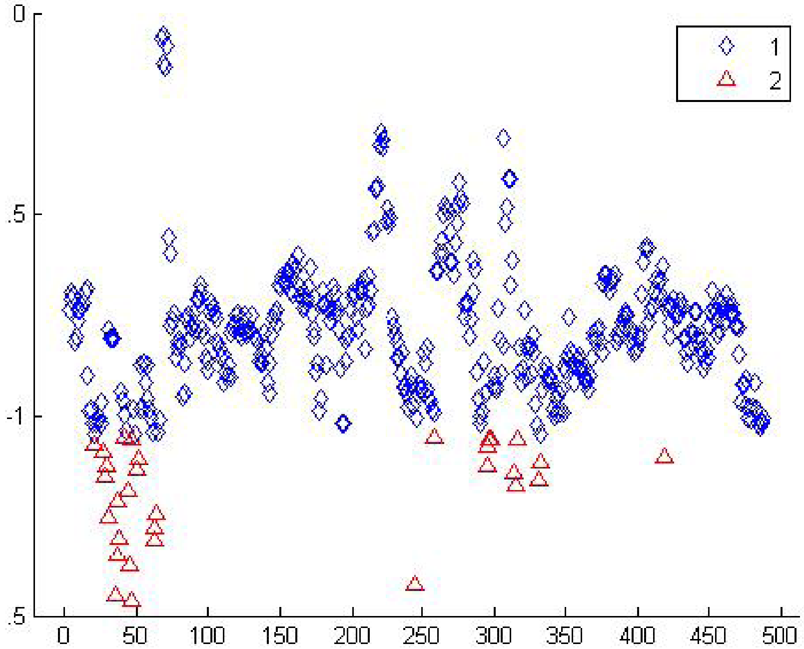
Implementation – UK-GE pair

The estimates are partly supporting the expectation; however the differcens between regimes are not significant when tested by the Wald statistics.

- The estimated γ is big and β_{VECM} and β_{TVECM} are far from 1;
- In the first regime the loading and the intercept of the GE equation are significant but very small;
- In the second regime the adjustment is not significant in the case of the UK equation, while It is significant and big for GE
- Wald tests do not evidence asymmetries

Implementation – UK-GE pair

Equilibrium term by regime



Estimates of loadings and intercepts, and information criteria

	VECM		TVECM			
			REGIME1		REGIME 2	
Equation1	coeff.	s.e.	coeff.	s.e.	coeff.	s.e.
λ	-0.04	-0.015	-0.022	-0.017	0.129	-0.132
μ	-0.049	-0.018	-0.02	-0.014	0.201	-0.166
Equation2						
λ	0.095	-0.015	0.072	-0.034	0.433	-0.203
μ	0.114	-0.018	0.061	-0.027	0.46	-0.234
AIC	-2736.992		-2743.507			
BIC	-2731.499		-2732.52			

Implementation – Testing for threshold

SupLM statistic shows significant (10% level) of threshold in three cases: Germany – France, Netherlands – France and UK – Germany pairs of prices.

- The number of simulations is set to 5000.

	UK-FR	GE-NE	GE-FR	UK-NE	NE-FR	UK-GE
$supLM$	17.470	15.537	18.755	18.296	22.289	16.851
$crit-val$	21.197	19.280	19.462	20.556	21.233	18.054
$p-val$	.191	.235	.065	.114	.034	.082

Robustness of the results

Threshold cointegration may originate from two non linearly integrated series that form the MMmodel introduced by Granger and Hyung (2006).

A partly linearized version of the model is given by:

$$\Delta_1 x_{1,t+1} = \max(a, b - z_t) + \varepsilon_{1,t+1}$$
$$\Delta_1 x_{2,t+1} = d + \varepsilon_{2,t+1}$$

where the relevant values are:

Threshold	Drift
b-a	a-d

Robustness of the results

In the present settings a generalization of the previous model can be used.

Formally:

$$\Delta_1 x_{1,t+1} = \min(a^+, b^+ - z_t)1(z_t > 0) + \max(a^-, b^- - z_t)1(z_t \le 0) + \varepsilon_{1,t+1}$$
$$\Delta_1 x_{2,t+1} = d + \varepsilon_{2,t+1}$$

The system above gives rise to three regions:

$$z_{t+1} \sim \mathrm{I}(0) \quad if \quad b^+ - a^+ \le z_t$$
$$z_{t+1} \sim \mathrm{I}(1) \quad with\, drift \quad if \quad b^- - a^- \le z_t < b^+ - a^+$$
$$z_{t+1} \sim \mathrm{I}(0) \quad if \quad b^- - a^- > z_t$$

Robustness of the results

- MM model results are consistent with the band of inaction hypothesis; however in general lead to different estimates of the thresholds.
  - Point estimates of the threshold are numerically close to TVECM's results in case of Germany – Netherland and Germany – France.
  - The hypothesis of symmetric behavior is supported by the results for UK-France and Netherland - France results.

Allowing for non-linear adjustment dynamics improves the accuracy of the model

- TVECMs have been used to examine the convergence in pairs of European electricity prices;
- The underlying idea is that adjustments toward the equilibrium may operate only when the (weighted) differences in forward prices exceed possible transaction costs and differences in the perceived risks;
- The empirical evidence support the initial hypothesis: out of six prices couples, four cases (Uk - France, Germany - Netherlands, Germany – France and Uk - Germany pairs) show a band of inaction for smaller deviations from the equilibrium inside a regime of cointegration;
- The tests statistic for the existence of thresholds are significant in three cases (Germany - France, Netherlands - France and UK-Germany);
- The achieved conclusions are robust to the use of different models;
- When compared based on BIC and AIC TVECMs show a superior performance to the linear VECM approach.

Further research

Interesting improvements of the research would include:

- Allowing for asymmetric thresholds and adjustments in all the models;
- Considering the chance that the thresholds vary over season;
- Consider all the prices in a single model instead of couples of prices.